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THERMODYNAMICS AND RELATIVITY[1]

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(1) INTRODUCTION

WE have met to do honor to the memory of Josiah Willard Gibbs. By the labors of this master, the classical principles of thermodynamics were given their most complete and comprehensive expression. As the subject for the tenth memorial lecture, it seems appropriate to discuss the extensions to these classical principles which have since been made necessary by Einstein's discovery of the special and general theories of relativity.

The need for an extension of thermodynamics to relativity arises in two ways.

In the first place the classical thermodynamics was —perhaps unintentionally but nevertheless actually— only developed for systems which were tacitly assumed to be at rest with respect to the observer, and further investigation is necessary for the treatment of thermodynamic systems which are moving relative to the spatial coordinates in use. This further investigation must be carried out with the help of those principles for the intercomparison of measurements—made by observers in uniform relative motion to each other—which form the subject-matter of the special theory of relativity.

In the second place, the older thermodynamics tacitly assumed that the behavior of thermodynamic systems could be described with the help of ideas as to the nature of space and time which we now know to be approximately valid only for a limited range of space-time and in the absence of strong gravitational fields. The considerations of the classical thermody-

[1] The tenth Josiah Willard Gibbs Lecture, delivered at Atlantic City, December 29, 1932, under the auspices of the American Mathematical Society, at a joint meeting of the society with the American Physical Society, and Section A of the American Association for the Advancement of Science.

namics were thus actually limited to the treatment of small enough systems and weak enough gravitational fields so that the deviations from this kind of space time could be neglected, and the Newtonian theory of gravitation could be applied as a close enough approximation. In order, however, to investigate the thermodynamic behavior of large portions of the universe as we may wish to do in connection with cosmological problems, and in order to obtain, even in the case of small systems, more precise expressions for the thermodynamic effects of gravity, it becomes necessary to extend thermodynamics to general relativity, and make use of the more valid ideas as to the nature of space and time and the more precise theory of gravitation which Einstein has now provided.

(2) The Character and Validity of Thermodynamics and Relativity

In carrying out these proposed extensions of thermodynamics to relativity, it proves possible to combine the known principles of thermodynamics with those of special and general relativity in a very natural manner with only small and apparently rational additions in the way of new hypothesis. Hence the character and validity of the system of relativistic thermodynamics that we obtain is largely dependent on the character and validity of the two component sciences.

In character, the classical thermodynamics may be regarded as a macroscopic, phenomenological science, which has no actual need for that interesting kind of support that can be furnished by the microscopic atomic considerations of statistical mechanics, but which attempts to treat the gross behavior of matter with the help of those generalized descriptions of the results of numerous gross experiments on the mechanical equivalent of heat and on the efficiency of heat engines, which we call the first and second laws of thermodynamics.

As to the validity of thermodynamics, we have feelings of great confidence, on account of the extensive experimental verification which exists, not only directly for the two laws themselves, but for an extraordinary number of consequences which have been drawn from them—often by elaborate but logical trains of deductive reasoning. Further additions to the principles of thermodynamics may be found, such as the newer so-called third law of Nernst and Planck, but we can not escape the conviction that, so long as the human mind retains its present ideas of rationality, these additions are likely to prove—as in the case mentioned—supplementary rather than destructive.

Relativity, a science which changes as it does our very ideas as to the nature of space and time, has much more fundamental and far-reaching implications than thermodynamics and can not be so easily characterized. There are, however, certain similarities between the two sciences which may be emphasized.

In the first place, at least in its present stage of development, relativity must also be regarded as a macroscopic theory dealing with ideas as to the nature of space and time which have been directly derived from macroscopic experiences. Indeed, in view of Heisenberg's uncertainty principle and the great difficulties which have been encountered in all attempts to construct a satisfactory relativistic quantum mechanics, we may even doubt whether these ideas as to space and time are even suitable for microscopic considerations. This, however, offers no difficulties if we are to combine with another macroscopic science such as thermodynamics.

In the second place, although we are often inclined to be specially impressed by the wonderful conceptual content of the theory of relativity, we may here emphasize its not negligible character as a phenomenological or descriptive science.

Thus the first of the two postulates of the special theory of relativity may be regarded as a generalized description of many failures to detect the absolute velocity of the earth's motion. And the second postulate may be regarded as a mere empirical statement of that constancy in the velocity of light, which is specially clearly demonstrated in the case of distant double stars by the lack of any effect from the changing motions of the members of the doublet on the time needed for their light to reach the earth.

Turning, moreover, to the two postulates necessary for the general theory of relativity, the principle of equivalence may be regarded not unfairly as a reasonably generalized description of Galileo's discovery that all bodies fall at the same rate. The principle of covariance, however, is on a somewhat different footing, since, as first pointed out by Kretschmann—given sufficient mathematical ingenuity—any physical law whatever could undoubtedly be expressed in covariant language the same for all coordinate systems, so that the principle of covariance can imply no necessary physical consequences. Nevertheless, as emphasized by Einstein, the actual phenomena of physics must themselves be independent of the choice of coordinate system which is a conceptual introduction on the part of the scientist which may be made in any way that may suit his convenience or please his fancy. Hence the actual employment of invariant forms of expression in searching for the appropriate axioms of physics is desirable in order to avoid the introduction of unsuspected assumptions which might otherwise be insinuated by the use of special coordinates. We can then also, somewhat facetiously, emphasize the phe-

nomenological character of the principle of covariance, by regarding it as a generalized description of the familiar phenomenon, that the purely conceptual activities of man—in inventing imaginary coordinate systems—are likely in first approximation to have no immediate effect on the laws of physics.

As to the validity of the theory of relativity, we have to rely on three different kinds of evidence.

In the first place, we may put its agreement with a great range of diverse facts from different branches of science, which as isolated phenomena can often be attractively explained in terms of pre-relativistic notions, but which as a whole have only been successfully correlated with the help of the theory of relativity.

In the second place, we must put those special observations which distinguish as uniquely as may be between the predictions of relativity and those which would result from other points of view. Here we have in the case of the first postulate of special relativity the demonstration of the Lorentz contraction by the Michelson-Morley experiment and all its now numerous repetitions, if we may include the extensive work of Professor Miller as demonstrating this contraction at least as the primary effect. And we also have the remarkable demonstration of Einstein's time dilation by the beautiful experiments of Kennedy and Thorndike. In the case of the second postulate of the special theory, we have as most important the precise analysis of double star orbits by de Sitter. And turning to the general theory of relativity, we have the entirely satisfactory results of the three crucial tests provided by the rotation of the perihelion of Mercury, the bending of light in passing the sun, and the shift in the wave-length of light originating on the surface of the sun and on that of the companion to Sirius.

Finally, as a third kind of evidence, for judging the validity of relativity we must not neglect the bearings of that wonderful internal coherence of the theory, with its simple foundation and elaborate but logical superstructure, which so well attests the genius of Einstein. Although such qualities can of themselves provide no guarantee as to correspondence with external phenomena, we can, nevertheless, regard them as indicating that such correspondence—when found for our present limited range of observation—is likely to persist over a much wider range of possible experience.

Like all parts of science, the theory of relativity will presumably be subject to future modifications and additions, such for example as might be provided by a successful unified field theory. Nevertheless, just as the Einstein theory has retained the Newtonian theory of gravitation as an exceedingly satisfactory first approximation, we may expect at least for a long time that such changes will here—as well as in the case of thermodynamics—be supplementary rather than destructive.

The character of the two sciences of thermodynamics and relativity, which we are going to combine, is thus sufficiently similar that we may have no hesitations, on that score, and may expect the resulting relativistic thermodynamics to be itself a macroscopic theory suitable for use in the description of the gross phenomena of the external world. And the validity of the two component sciences is sufficiently established so that for the present we may concentrate attention, as we shall in what follows, on the rationality of that small amount of additional hypothesis which we must introduce to effect the combination.

(3) The Extension of Thermodynamics to Special Relativity

We are now ready to consider the actual procedure adopted in the extension of thermodynamics, first to special relativity and then to general relativity. The extension to special relativity, so as to obtain a suitable thermodynamic theory for moving systems, was made by Planck[2] and by Einstein,[3] as early as the year 1907, in that brilliant period of development which was initiated by Einstein's publication of the elements of special relativity only two years previous.

(*a*) *Special Relativity and the First Law of Thermodynamics.* In order to appreciate the nature of this extension, let us begin by seeing what happens to the first law of thermodynamics when the extension is made.

In the classical thermodynamics for systems at rest with respect to the observer, we have found it important to distinguish two ways in which there can be an interchange of energy between a system and its surroundings, namely, through the flow of heat into the system from its surroundings and through the performance of work by the system on its surroundings. Making use of this distinction, and making use of the principle of the conservation of energy, which requires that any alteration in energy content can only result from interchange with the surroundings, we then write the first law of thermodynamics in the form given by the equation (1)

$$\Delta E = Q - W \qquad (1)$$

where ΔE is the increase in the energy of the system which accompanies the influx in heat Q and the performance of work W against external forces.

In *form* this equation can be taken over without modification into the thermodynamics of moving sys-

[2] Planck, Berl. Ber. (1907) p. 542; *Ann. der Phys.*, 26: 1, 1908.
[3] Einstein, *Jahrb. f. Rad. u. El.*, 4: 411, 1907.

tems, in the first place since the special theory of relativity has done nothing to upset the principle of the conservation of energy, and in the second place since we shall still wish to distinguish between the energy transfer W corresponding to work done against macroscopic external forces and the other modes of transfer which we call the flow of heat Q.

In the application of this equation to moving instead of stationary systems, however, an important difference—which would not have been suspected in prerelativistic days—now arises on account of the relations between mass, energy and momentum made clear by Einstein's work. To illustrate this difference, let us consider—as we usually do in thermodynamics—only very simple systems consisting of a given amount of thermodynamic fluid or working substance which exerts a pressure on its surroundings.

If such a system is *at rest,* the only way it can do work on its surroundings is by a change in volume under this pressure, and the application of the first law equation (1) then gives us simply

$$dE_o = dQ_o - p_o dv_o \qquad (2)$$

where the subscript $(_o)$ has been added to indicate that the quantities involved are all referred to coordinates in which the system is at rest.

If such a system is *in motion,* however, its momentum will in general change with its energy content even though we hold the velocity constant, owing to the special relativity relation which associates mass with energy. Hence in applying the first law equation to moving systems, even in the simple case of constant velocity, we shall have to include, in addition to the work done against external pressure, the work done against the external force involved in the change in momentum. We must then write in general

$$dE = dQ - p\,dv + \bar{u} \cdot d\bar{G} \qquad (3)$$

where the last term is the scalar product of the velocity of the system $\bar{u}$ and its change in momentum $d\bar{G}$. Moreover, in making use of this equation we must employ the special relativity relation connecting the momentum of the system with its energy flow

$$\bar{G} = \frac{E + p\,v}{c^2}\bar{u} \qquad (4)$$

where c is the velocity of light, and the term $\frac{E\bar{u}}{c^2}$ gives the momentum due to the transport of the energy of the system as a whole, and the term $pv\bar{u}/c^2$ corresponds to the additional flow of energy resulting from the work done on the moving volume by the action of the external pressure.

With the help of these two expressions for the first law (3), and for the momentum of a moving system (4), we can then obtain transformation equations which will give us expressions for all the quantities, involved in the application of the first law to moving systems, in terms of the analogous quantities as they would be measured by a local observer moving with the system. In accordance with the known equations for force, and the Lorentz contraction for moving volumes, we are already provided by the special theory of relativity with the simple transformations for pressure and volume

$$p = p_o$$
$$v = v_o \sqrt{1 - u^2/c^2} \qquad (5)$$

Furthermore, considering first an adiabatic acceleration in which the velocity of our system is changed without flow of heat or change in internal condition as measured by a local observer, and then considering more general processes in which flow of heat is permitted, we readily obtain as the transformation equations for energy and heat the two expressions

$$E = \frac{E_o + p_o v_o}{\sqrt{1 - u^2/c^2}}$$
$$dQ = dQ_o \sqrt{1 - u^2/c^2} \qquad (6)$$

This gives all the apparatus necessary for the application of the first law of thermodynamics to moving systems. It is to be specially noted that so far no new assumptions, beyond those already present in the mechanics of special relativity, have been introduced into our systems of thermodynamics, except, if you wish, our procedure in still giving the name heat to that part of the energy transfer which does not take place through the work done against macroscopic external forces.

(*b*) *Special Relativity and the Second Law of Thermodynamics.* Let us now turn to the more characteristically thermodynamic considerations involved in the application of the second law of thermodynamics, and examine the fate of this principle when the extension to special relativity is made.

In the classical thermodynamics the full content of the second law could be conveniently condensed into the very simple expression

$$\Delta S \geqq \int \frac{dQ}{T} \qquad (7)$$

where the left-hand side gives the increase in the entropy content S when a system changes from one state to another, and the right-hand side is to be obtained by dividing each element of heat dQ absorbed by its temperature T, and summing up for the whole process by which the system changes from its initial to its final state.

The sign of equality (=) in this expression applies to reversible processes which take place with that highest possible efficiency, which would just be sufficient to permit a return *both* of the system and its surroundings to their original state. And the sign of

inequality (>) applies to those less efficient, actual processes which we ordinarily encounter in nature. With the help of the relation of equality we can then calculate the entropy of any system by considering an ideal reversible process by which it could be brought from its standard state to the state under consideration. And with the help of the two relations of equality and inequality, we codify all that extraordinary range of information as to the equilibrium and efficiency of physical-chemical processes which is subservient to the second law.

In making the extension to special relativity, it was found possible to take over this expression for the second law of thermodynamics as a postulate without any change at all in form. And this was evidently a rational thing to try to do, since it preserves the constancy of entropy for purely mechanical processes, makes the increase of entropy for reversible thermal processes dependent on the transfer of energy in forms other than work, and retains with the help of the sign of inequality those opportunities for irreversibility and spontaneous increase in entropy which lie at the heart of thermodynamic considerations.

In applying this expression to moving systems we must of course substitute values for entropy, heat and temperature which are appropriate for a moving system, and hence shall desire transformation equations which will permit us to calculate these quantities in terms of the analogous quantities which would be directly measured by a local observer traveling with the system in question.

In the case of heat, we are already provided by the application of the first law with the transformation equation

$$dQ = dQ_0 \sqrt{1 - u^2/c^2} \qquad (8)$$

In the case of entropy, we are then directly led by the postulate itself to the conclusion that the entropy of a system must be an invariant for the Lorentz transformation

$$S = S_0 \qquad (9)$$

owing to the possibility of changing the velocity of a system by a quasi-static reversible adiabatic acceleration, which leaves the internal state and proper entropy S_0 unaltered on account of the quasi-static character of the acceleration, and leaves the entropy S unaltered on account of the reversible and adiabatic character of the acceleration. This invariance of entropy is, moreover, in evident agreement with the statistical mechanical interpretation which relates the entropy of a system to the probability of its state, a quantity which could hardly be a function of the velocity with which the observer happens to be moving past the system.

Finally in the case of temperature, by combining the requirements of the postulate itself with the two transformation equations already obtained, it is evident that we are now necessarily led to the relation

$$T = T_0 \sqrt{1 - u^2/c^2} \qquad (10)$$

in order that the postulated law (7) may apply to the description of a given change in state both from the point of view of a local observer moving with the system and from the point of view of other observers with respect to which the system is in motion.

(*c*) *Discussion of the Extension to Special Relativity.* This completes all that is necessary for the extension of thermodynamics to special relativity.

It will be seen that the additions in the way of new hypotheses, beyond what is already contained in the special theory of relativity and in the classical thermodynamics, have really been very small and apparently rational. Indeed, it seems fair to say that these additions consist solely in the assumption that the second law of thermodynamics, as expressed in the usual well-known form given by (7) will not break down when we turn to the consideration of moving systems, and that the quantity dQ occurring in this expression must still be interpreted as that part of the energy transfer which can not be considered as work done against macroscopic external forces.

It should also be noted that the results which are given by this extended theory are entirely coherent with the accepted body of theoretical physics. For example, the application of this theory to determine the dynamical properties of a moving enclosure filled with black-body radiation leads to the same results as were originally obtained by Mosengeil[4] from strictly electromagnetic considerations. And the transformation equation given for heat (6), which we have regarded as derived from an application of the mechanics of special relativity to the behavior of a portion of fluid, agrees with that which can be derived from electromagnetic considerations for the Joule heating effect in a moving electrical conductor. Most important of all, however, it should be noted that the extension has been so devised that any predictions, which we make with its help as to the behavior of a given system moving with a *constant* velocity u, will completely agree with those which would be made with the help of the classical thermodynamics by a local observer who moves along with the system in question.

It is important to emphasize these qualities of rationality and coherence, since our judgment as to the validity of this extension of thermodynamics must be largely based thereon. Any direct test of the extension would for the present be out of the question,

[4] Mosengeil, *Ann. d. Phys.*, 22: 867, 1907. The results of Mosengeil were employed by Planck in his method of obtaining the extension of thermodynamics to special relativity.

since all the various thermodynamic quantities for moving systems were found to differ from the analogous ones for stationary systems only by terms of the order of u^2/c^2 or higher, and we could only expect differences of this practically undetectable order for any thermodynamic theory of moving systems that might be proposed.

The usefulness of the extension consists partly in the ease with which we can now treat problems by simple thermodynamic methods which would otherwise involve complicated kinetic theory or electromagnetic considerations, as in the case of the moving enclosure filled with radiation. The usefulness of the extension depends mainly, however, on the increased insight which we now have into the nature of thermodynamics and thermodynamic quantities. Thus the invariance to the Lorentz transformation for entropy and for the ratio of heat to temperature provided by the special theory of relativity prove essential for the further extension of thermodynamics to general relativity to which we must now turn.

(4) The Extension of Thermodynamics to General Relativity

In the general theory of relativity, the space-time continuum in which physical events take place is regarded as characterized by the formula for interval

$$\begin{aligned} ds^2 &= g_{11}\,dx_1^2 + 2\,g_{12}\,dx_1\,dx_2 + \ldots + g_{44}\,dx_4^2 \\ &= g_{\mu\nu}\,dx^\mu\,dx^\nu \qquad (g_{\mu\nu} = g_{\nu\mu}) \end{aligned} \tag{11}$$

where x_1, x_2 and x_3 are the three spatial coordinates that are being used, x_4 is the temporal coordinate, and the $g_{\mu\nu}$ are the ten gravitational potentials. The dependence of these gravitational potentials on the distribution of matter and energy is given by Einstein's ten field equations

$$-8\pi T^{\mu\nu} = R^{\mu\nu} - \tfrac{1}{2} R g^{\mu\nu} + \Lambda g^{\mu\nu} \tag{12}$$

where $T^{\mu\nu}$ is the energy-momentum tensor, $R^{\mu\nu}$ and R are obtained from the Riemann-Christoffel tensor by contraction, and Λ, the so-called cosmological constant, is a quantity which is observationally known in any case to be exceedingly small when expressed in reciprocal square centimeters, and may well be zero. Finally, the motion of free particles and light rays in this space-time continuum is determined by the equation

$$\delta \int ds = 0 \tag{13}$$

with ds greater than zero for material particles and equal to zero for light rays.

The results predicted by these fundamental equations of general relativity are in satisfactory agreement with all the facts that are now at our disposal, and in particular agree with the astronomical observations which have furnished the three crucial tests of relativity.

In order to include thermodynamics within this framework, we must now inquire into the analogues in general relativity of the ordinary first and second laws of thermodynamics.

(*a*) *The Analogue of the First Law in General Relativity.* In the case of the first law the procedure to be adopted is clear. In the classical thermodynamics the first law was an expression of the principle of the conservation of energy as applied to small stationary systems in the absence of a gravitational field, and in relativistic thermodynamics we must evidently use as the analogue of the first law the more general energy-momentum principle provided by relativistic mechanics.[5]

This principle can be expressed by the very simple *tensor* equation

$$(T^{\mu\nu})_\nu = 0 \tag{14}$$

and may be regarded as an immediate result of Einstein's field equations (12), since the tensor divergence of the expression there given for the energy-momentum tensor $T^{\mu\nu}$ can be shown to be necessarily identically equal to zero. For purposes of computation it is often more convenient to rewrite this equation in the *tensor density* form

$$\frac{\partial \mathfrak{T}_\mu^\nu}{\partial x^\nu} - \tfrac{1}{2}\,\mathfrak{T}^{\alpha\beta}\frac{\partial g^{\alpha\beta}}{\partial x^\mu} = 0 \tag{15}$$

and to obtain an insight into the nature of the principle, it is sometimes useful to rewrite it in the form of an ordinary divergence as expressed by the non-tensor yet nevertheless *covariant* equation

$$\frac{\partial}{\partial x^\nu}(\mathfrak{T}_\mu^\nu + \mathfrak{t}_\mu^\nu) = 0 \tag{16}$$

where the pseudo-tensor density of potential energy and momentum $\mathfrak{t}_\mu^\nu$ is defined for *all systems* of coordinates in such a way that we can substitute $\partial \mathfrak{t}_\mu^\nu/\partial x^\nu$ for the second term of (15).

To remind us of the physical significance of these familiar equations of relativistic mechanics, it will be recalled that the equations reduce in the absence of a gravitational field to the ordinary principles of special relativity for the conservation of the energy and momentum directly associated with matter and radiation. In general, however, in the presence of gravitational fields, it will be evident from the third form (16) in which the equations have been written that they will lead to conservation laws only when we include—along with the energy and momentum directly associated with matter and radiation—the potential energy and momentum of the gravitational field, which corresponds to the presence of the pseudo-tensor density $\mathfrak{t}_\mu^\nu$ in the equation in this form (16).

This general result proves to be of great importance

[5] Tolman, *Proc. Nat. Acad.*, 14: 268, 1926; *Phys. Rev.*, 35: 875, 1930.

for relativistic thermodynamics by permitting—even in the case of isolated systems—an increase in the energy directly associated with matter and radiation at the expense of the potential energy that we assign to the gravitational field. For example, if we consider a system composed of a perfect fluid having the proper macroscopic density of energy ρ_{00} and proper pressure p_0 as measured by a local observer at the point of interest, and having no flow of heat, it is known that we can write

$$T^{\mu\nu} = (\rho_{00} + p_0)\frac{dx^\mu}{ds}\frac{dx^\nu}{ds} - g^{\mu\nu} p_0 \qquad (17)$$

as an expression for the energy-momentum tensor. And if we substitute this expression into the above equations of relativistic mechanics, we can obtain for any infinitesimal element of the fluid of proper volume δV_0, the relation

$$\frac{d}{dt_0}(\rho_{00}\,\delta V_0) + p_0\frac{d}{dt_0}(\delta V_0) = 0 \qquad (18)$$

From one point of view there is nothing surprising about this result since it merely states that a local observer who examines the behavior of an element of the fluid small enough so that the gravitational "curvature" of space-time can be neglected will find the rate of change in energy content related in the expected way to the work done against the external pressure. From another point of view, however, as this same equation can be applied to each one of all the elements into which the total fluid of the system can be divided, the result may seem somewhat surprising, since it leads to the possibility of systems in which the proper energy of every element of the fluid may be simultaneously decreasing or increasing, according as the system is expanding or contracting. Moreover, since it is this proper energy immediately associated with matter and radiation which determines the possibilities for entropy increase, we shall later find in relativistic thermodynamics an escape from certain restrictions imposed in the classical thermodynamics by the usual form of the principle of the conservation of energy.

Just as in the previous case of special relativity, we note that the extension of thermodynamics to general relativity involves, so far as the first law is concerned, no new hypothetical material beyond that already contained in relativistic mechanics. And we may now turn to the relativistic analogue of the second law of thermodynamics.

(*b*) ***The Analogue of the Second Law in General Relativity.*** To guide us in obtaining a suitable postulate to serve as the relativistic second law of thermodynamics, we must make use of the two fundamental ideas of general relativity which are expressed by the principles of covariance and equivalence. In accordance with the principle of covariance, our postulate must be expressed in covariant form the same for all coordinate systems, to avoid the danger of being influenced in its selection by a spurious simplicity when referred to some particular system of coordinates. And in accordance with the principle of equivalence, our postulate must reduce to the thermodynamic requirements of special relativity, when applied to an infinitesimal element of fluid using natural coordinates for the point of interest.

These two principles have been sufficient to lead with considerable confidence to the expression[6]

$$\frac{\partial}{\partial x^\mu}\left(\phi_0\frac{dx^\mu}{ds}\sqrt{-g}\right)\delta x_1\,\delta x_2\,\delta x_3\,\delta x_4 \geqq \frac{\delta Q_0}{T_0} \qquad (19)$$

as the appropriate postulate to take as the relativistic analogue of the ordinary second law of thermodynamics. The quantity ϕ_0 in this expression is the proper entropy density of the thermodynamic fluid under consideration as measured at the point of interest by a local observer; the quantities dx^μ/ds are the components of the macroscopic "velocity" of the fluid at that point; and the other quantities on the left-hand side of the expression have their usual significance. The significance of the right-hand side of the expression is more difficult to grasp, and will be specially treated in a forthcoming article by Professor Robertson and myself.[7] The quantity δQ_0 may be taken as the heat—measured by a local observer at rest in the fluid at the point of interest—which flows into an element of the fluid having the instantaneous proper volume δV_0 during the proper time δt_0 where these quantities are so chosen as to make

$$\delta V_0\,\delta t_0 = \sqrt{-g}\,\delta x_1\,\delta x_2\,\delta x_3\,\delta x_4 \qquad (20)$$

and the quantity T_0 is taken as the temperature ascribed to this heat by the local observer.

The two signs of equality (=) and inequality (>) in the expression refer respectively to the two cases of reversible and irreversible processes, and in applying the principle to irreversible processes we are to regard an increment in coordinate time δx_4 as positive when taken in the direction to correspond to a positive increment in proper time δt_0 as measured in the ordinary manner by a local observer.

To show the agreement of this postulated expression for the relativistic second law with the principle of covariance, we have merely to note that it is a tensor equation of rank zero—both sides being scalar invariants—and hence is true in all coordinate systems if true in one. To show its agreement with the principle of equivalence we must see what it reduces to in natural coordinates for the point of interest. Intro-

[6] Tolman, *Proc. Nat. Acad.*, 14: 268, 701, 1928; *Phys. Rev.*, 35: 896, 1930.

[7] Tolman and Robertson, submitted to the *Physical Review* for publication.

ducing such coordinates x, y, z, t, *and making use of the transformation equations for entropy, heat and temperature provided by the special theory of relativity,* we find, however, that our principle then reduces to

$$\left[\operatorname{div}(\phi\bar{u}) + \frac{\partial\phi}{\partial t}\right]\delta x\,\delta y\,\delta z\,\delta t \geqq \frac{\delta Q}{T} \qquad (21)$$

where ϕ, $\bar{u}$, δQ and T are now the quantities referred to our present coordinate system which we ordinarily designate as entropy density, velocity, heat absorbed and temperature. And we see that this result does relate the change in the entropy of the element of fluid, instantaneously contained in the coordinate range $\delta x\,\delta y\,\delta z$, to the absorbed heat and temperature in the way

$$\frac{d}{dt}(\phi\,\delta x\,\delta y\,\delta z)\,\delta t \geqq \frac{\delta Q}{T} \qquad (22)$$

which is required by the second law of thermodynamics in special relativity.

At the present stage of observational knowledge, our belief in the validity of the proposed postulate is primarily based on this agreement with the two principles of covariance and equivalence. In addition, however, it may be emphasized that the principle has been chosen so as to be simply the immediate covariant re-expression of the special relativity form of the second law (21); and past experience has shown, notably, for example, in the cases of the fundamental formulae for space-time interval and geodesic trajectory, that these simplest possible covariant generalizations when feasible are likely to be correct. Furthermore, it may be remarked that the conclusions which have so far been drawn from this extension of thermodynamics to general relativity appear—at least after due reflection—to be reasonable and illuminating.

It must be emphasized, nevertheless, that these qualities are not sufficient to prove the validity of the postulate, since other covariant expressions might be found which would also reduce to the special relativity law in natural coordinates. Hence the postulate must be regarded as a real generalization with a range of validity to be finally determined only by the correspondence between observation and prediction.

(To be concluded)

STUDIES IN NUCLEAR PHYSICS

By Dr. JNO. A. FLEMING

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STUDIES IN NUCLEAR PHYSICS

THE Carnegie Institution of Washington announced on February 2 in a lecture by Dr. M. A. Tuve before the Franklin Institute on "The Atomic Nucleus and High Voltages," the results of the past year's work at the high-voltage laboratory of its Department of Terrestrial Magnetism in Washington. This program of investigations constitutes the present expression of a long-continued policy of the department of undertaking laboratory studies of the basic physical phenomena which underlie all large-scale manifestations of magnetism and electricity, as complementary to its field and observatory operations and theoretical investigations. These laboratory studies are now directed toward studies of the simplest cases of the interaction at close distances of the known primary material particles—the electron and proton, which have both electric charge and magnetic moment—and their simplest combinations.

During the past year Dr. Tuve and his colleagues, L. R. Hafstad and O. Dahl, have obtained results covering a variety of experiments in nuclear physics, including a verification of the existence of the recently discovered neutron, observations on the resonance-disintegration of aluminum by polonium alpha-particles, and studies of the disintegration of lithium and boron, using high-speed protons from a high-voltage tube. The Van de Graaff type of electrostatic generator, a simple metal sphere charged to a high voltage by a silk belt, was tested, developed and used for the atomic disintegration-studies. A special building is now under construction at the department to house a large (2-meter) generator of this type which was built at the department and tested during May, 1932. This equipment promises to give an intense source of artificial neutrons, this being one of the most interesting of its numerous potentialities. It will provide 10 microamperes or more of protons or helium-ions having energies above 1,500,000 electron-volts.

The existence of the non-classical phenomena at present explained on the neutron-hypothesis was verified in the department's laboratory last September by a repetition of the main features of Chadwick's experiments. Using a 3-mc polonium source bombarding beryllium, recoil-nuclei of nitrogen were found to produce a maximum of nearly 50,000 ions in the 15-mm ionization-chamber of a valve-counter of the type used by Chadwick. Recoil-nuclei were observed with this instrument and with the FP-54 pliotron connected to a small chamber and used in the same way as Pose has used the duant electrometer. The

range of the recoil-protons was found to be about 44 cm in agreement with Chadwick's result. Several thousand stereoscopic photographs were made with the neutron-source mounted in a Wilson cloud-chamber, as in Feather's experiments, and the recoil-nuclei were identified and measured. Disintegration-phenomena in the chamber were not definitely assigned to neutrons because of the weakness of the source, but will be studied shortly using a much larger quantity of polonium. The absorption of the beryllium neutrons by one inch of lead, measured by counts of recoil-protons, was found to be about 55 per cent., in disagreement with Chadwick's 13 per cent. (measured by nitrogen-recoils), but agreeing with the value published in October by Thibaud and La Tour.

As a necessary safeguard to the validity of results with the high-voltage technique, as well as by reason of their intrinsic value, it was decided two years ago to carry out certain experiments using radioactive sources. One feature of this program was the development and test of instruments and methods for nuclear observations. The limits of sensitivity of the FP-54 pliotron have been investigated, and it has been utilized for measurements on high-speed protons produced by disintegrations and by neutron-recoil. A single-tube circuit using an FP-54 in an evacuated case achieves a charge-sensitivity limited only by the statistical fluctuation (± 640 e) of the grid-current (10^{-15} ampere) of the tube, and the latter imposes a usable limit with this device not inherent in a true electrometer, although the much higher voltage-sensitivity is an advantage in many applications. Because of this fluctuation the minimum steady current theoretically observable is approximately 3×10^{-19} ampere (2 electrons per second), and by actual test a current of 5×10^{-18} ampere (30 electrons per second) is directly measurable in a time of several minutes. On the basis of experience with a cloud-chamber similar to that described by Blackett, an improved form was constructed, which has several important advantages over the usual form utilizing a piston and a liquid seal. A large-diameter flexible metal "sylphon" bellows is used, giving a chamber entirely free from leakage, with resulting constancy of expansion ratio and gas composition, which can be oriented vertically or in any other direction at will. A modified form of mercury spark-lamp provides sufficient illumination to enable the use of cinema positive film, with a very considerable gain in resolving power and contrast over the usual negative emulsion. A valve-counter of the type described by Wynn-Williams and Ward was developed, which is simple in construction and singularly insensitive to external disturbances, operating satisfactorily in the presence of the noise and electrical disturbances produced by the Van de Graaff generator. The useful amplification of such a device being limited solely by the noise-level of the early stages, this factor was investigated. The resulting amplifier has a noise-level comparable to the theoretical noise-level due to the Johnson effect (thermal agitation of electrons in a resistance) of the plate-impedance of the input-valve.

One problem of importance in radioactive research which was selected for attack is that of resonance-disintegration of the nucleus. Using the FP-54 in the same way as Pose has used the duant electrometer, Mr. Hafstad has studied the resonance-disintegration of aluminium. This work is only partially completed, but has progressed to a point where there can be no doubt of the existence of the phenomenon. Steudel's failure to observe it is not surprising in view of the geometry of his apparatus, and in contradiction to his results Mr. Hafstad finds that the "disintegration-yield" in his experiments, on the basis of an absolute calculation, checks Pose's high value. Details of the sharpness of resonance and other features are still under investigation.

Having experimented in this laboratory since 1926 with high voltages from spark-excited Tesla coils applied to vacuum-tubes, chiefly by reason of the lack of funds for a more suitable voltage-source, we were glad to adopt the inexpensive electrostatic type of generator for high voltages in air devised by Dr. R. J. Van de Graaff a year and a half ago. A generator of this type was built by the department a year ago, using a 2-meter aluminum sphere, charged by a 6-inch silk belt, and potentials as high as 2,000,000 volts were obtained in tests out-of-doors. Sufficient laboratory space not being available for immediate use of this generator, a 1-meter generator was assembled, and this has been used with a 23-section cascade-type vacuum-tube formerly used in the Tesla coil work. One interesting feature is the focusing action of such a tube, which approaches 100 per cent. for currents of 0.5 microampere of hydrogen- or helium-ions at 600 kv, although there is only a 2-cm diameter hole down the 5-foot tube. A hollow-anode, low-voltage arc (suggested by Dr. E. S. Lamar) is used for the ion-source, mounted inside the sphere and with the necessary power supplied by generators driven by the silk belt which charges the sphere. With this apparatus the disintegration of lithium and boron by high-speed protons has been investigated. With a very thin mica window on the tube near the target, the alpha-particles produced by the disintegrating nuclei have been identified and recorded by the linear amplifier (valve-counter) mentioned above. Lithium is found to give two ranges of alpha-particles in

approximately equal numbers, the shorter range being just under two centimeters. The disintegration-yield from boron is roughly twenty times that of lithium at 600 kilovolts, and the majority of these alpha-particles have a range of nearly 3 cm, with a much smaller number having a longer range. Preliminary measurements indicate that for boron about 4,000,000 protons are required to produce one disintegration at 600 kilovolts. These results are in approximate agreement, both as to ranges and disintegration-yields, with those recently reported in *Nature* by Cockroft and Walton.

Dr. Tuve's lecture will be published in the *Journal of the Franklin Institute*.

OBITUARY

TIMOTHY E. WILCOX

BRIGADIER-GENERAL TIMOTHY E. WILCOX, retired Army surgeon, living in Washington, D. C., died on December 10, at the age of ninety-two years. He was born at North Litchfield, New York, on April 26, 1840. He graduated from Union College in 1861 with an A.B. and received the A.M. degree in course.

A brief tour with McClellan's army ended with typhoid fever. His medical studies were resumed and he received M.D. from the Albany Medical College in 1864. He was immediately appointed assistant surgeon of the 6th New York Heavy Artillery. He attended Jefferson Davis during his detention at Fortress Monroe after the Civil War. He was appointed assistant surgeon in the regular army in May, 1867, retiring as brigadier-general in April, 1904. In November, 1898, he went to Cuba as lieutenant-colonel chief surgeon and was honorably discharged in May, 1899.

General Wilcox was a born naturalist. Everything was fish to his net—plants, animals, minerals, insects, worms, reptiles, fossils, etc. The National Museum and other museums received many rare specimens from him. The fossil horns of a tiny deer and those of a primeval ox are in the National Museum. The snake *Tontilla Wilcoxii* Stejneger was from Arizona. *Townsendia Wilcoxiana* Wood was discovered at Camp Supply, Indian Territory, in the seventies. *Primula Wilcoxii* Wood (?) was from Fort Boise, Idaho. *Panicum Wilcoxiànum* Vasey was collected in Nebraska, *Quercus Wilcoxii* Rydberg and a cactus from Fort Huachuca, Arizona. His article in *Nature* in 1879–80 calling attention to the absence of angle worms around Boise, Idaho, caused much comment. He was author of occasional notes and papers in medical and other journals. From 1917 he was nearly blind, but his mind was clear to the end.

General Wilcox belonged to Phi Beta Kappa, Alpha Delta Phi, the Cosmos Club, Biological Society of Washington and the National Geographic Society. He joined the Torrey Botanical Club in 1880, being proposed by Dr. Alphonso Wood. In 1930, after 50 years membership, he was made a life member of the club.

WILLARD W. EGGLESTON
BUREAU OF PLANT INDUSTRY
WASHINGTON, D. C.

RECENT DEATHS

W. ALBERT MANDA, of Orange, New Jersey, a well-known horticulturist, died on March 15, at the age of seventy years.

GILBERT CHARLES BOURNE, emeritus professor of zoology and comparative anatomy at the University of Oxford, died on March 9, at the age of seventy-one years.

DR. ROBERT INNES, formerly astronomer for the Union of South Africa, died suddenly on March 14, at the age of seventy-one years.

WILLIAM CAWTHORNE UNWIN, the British engineer, died on March 17, at the age of ninety-four years.

Nature records the deaths of Dr. C. A. Barber, lately lecturer in tropical agriculture at the University of Cambridge, aged seventy-two years; of Sir Benjamin Gott, chairman of the Commission on Educational and Cultural Films, and formerly head master of the Cheltenham School of Science, aged sixty-seven years, and of Mr. J. J. F.-X. King, the Scottish entomologist, aged seventy-seven years. Mr. King had presented his main collection of British insects to the University of Glasgow. The university is now to receive under his will the portrait of Mr. King painted by Forrester Wilson and the remainder of his collections, together with his library of books on natural history.

SCIENTIFIC EVENTS

REPORT OF THE COUNCIL FOR CHEMISTRY

IN its report for 1932, according to a summary given in *Nature*, the Federal Council for Chemistry refers with regret to the necessary postponement of the ninth International Congress of Pure and Applied Chemistry and the eleventh conference of the International Union of Chemistry, which were to have been held in Madrid in 1932. The next meeting of the union will take place in the spring of 1934 in Madrid,

and not in Switzerland, as previously arranged. During the year, the Verein Oesterreichischer Chemiker and the Svenska National Kommitten för Kemie were elected members of the International Union. The report refers to a conference on chemical documentation, held in Paris in October, 1932, and indicates that the Federal Council and the Division of Chemistry and Chemical Technology of the U. S. National Research Council are in complete agreement with regard to certain criticisms of the activities of the International Committee dealing with the reform of biochemical nomenclature. The efforts of the British Standards Institution to extend the use of the words "British Standard" to include "chemical substances used in manufactures, photography or philosophic research and anti-corrosives" were supported by the Federal Council. The Board of Trade agreed to the institution proceeding with an application to register provided that it was in a position to submit support from the appropriate trade association or similar body. The report says: "In October, a committee consisting of Dr. E. F. Armstrong, E. R. Bolton, Dr. L. H. Lampitt, Professor G. T. Morgan, Emile Mond, Professor J. C. Philip, Sir William Pope, J. Davidson Pratt and D. Rintoul was appointed 'To consider how the resources of the various bodies concerned with the professional and scientific welfare of chemists can be most economically and efficiently utilized.' This committee has met on several occasions, and will present, early in 1933, a report on its findings for consideration by the Federal Council."

THE YALE NORTH INDIA EXPEDITION

THE last chapter of one of the greatest geological events in the earth's history, resulting in the elevation of the Himalayan mountains, was witnessed by prehistoric man, according to evidence uncovered by the Yale North India Expedition, led by Dr. Hellmut de Terra, research associate in geology at Yale University. The expedition, which also included Mrs. de Terra, Professor G. E. Hutchinson, of the department of biology, and Mr. G. E. Lewis, paleontologist, has just returned to New Haven after spending the past fifteen months in the Himalayas.

Traces of prehistoric man in the form of knives, scrapers and other implements and the remains of a mammoth, whose former existence in the Himalayas has been hitherto unsuspected, comprised two of the more important finds made by the expedition. The geographical, geological and zoological information obtained is expected, it is said, to change present ideas about the early history and origin of the world's highest mountains.

Dr. de Terra has issued a statement in regard to the exposition in which he says:

> The paleolithic implements and the mammoth were found in formations that had been thrown into earth folds during the upheaval and indicate that prior to that time the southern Himalayas were considerably lower in altitude. The rise of the Himalayan range must have continued into historical times. The present high relief of the mountains is a recent achievement and ancient man looked upon a Himalayan range of quite a different appearance from that which modern man sees. We have found proof that prehistoric man in Northern India must have witnessed the last great mountain-making event, which resulted in the present great height of the Himalayas and neighboring high ranges.

The collections made by the expedition have just arrived at New Haven, where most of them will be placed in the Peabody Museum of Yale University. The members of the expedition will complete their investigations here by further study of the finds and their relation to their environment.

ANNIVERSARY OF THE PHILADELPHIA COLLEGE OF PHARMACY AND SCIENCE

THE one hundred and twelfth anniversary of the founding of the Philadelphia College of Pharmacy and Science was celebrated on February 23 with a special convocation at which the honorary degree of master of pharmacy was conferred upon Dr. George Denton Beal, one of the directors of the Mellon Institute of Industrial Research at Pittsburgh. Dr. Beal then delivered at the exercises an address on "Advances in Pharmacy through Scientific Research," in which he reviewed the relation of pharmacy to other sciences and pointed out many instances of the ways in which the practise of pharmacy has stimulated research and scientific advancement not only in pharmacy but also in chemistry, bacteriology, biology and physiology.

The evening of Founders' Day at the College was featured by a testimonial banquet to Professor Frank Xavier Moerk, who is completing his fiftieth year as a member of the teaching staff at the Philadelphia College, where he is at the head of the department of analytical chemistry and is one of the executive officers of the faculty. Dr. Lewis C. Scheffey, 1915, Philadelphia physician who is president of the Philadelphia College Alumni Association, acted as toastmaster.

A feature at the testimonial banquet was the graphic portrayal by undergraduates in the dramatic society of outstanding events in Professor Moerk's career. This dramatic presentation was arranged by Registrar John E. Kramer, 1925. Felicitations of the board of trustees were extended by Professor Joseph W. England, 1883, its chairman, who is head of the scientific department of the Smith, Kline and French laboratories. Dr. Henry V. Arny, 1889, dean of

Columbia University College of Pharmacy, greeted Professor Moerk as one of his most distinguished students. For the faculty of the Philadelphia College, Dean Julius W. Sturmer spoke of his many years' association with Professor Moerk. An address was also made by Dr. B. Franklin Stahl, trustee of the college.

Presentations were made by Henry Brown, of Scranton; Frank P. Kelly, Jr.; Arthur Osol and James Q. Mackey.

The climax of the evening was the unveiling of an oil portrait of Professor Moerk which was presented to the Philadelphia College by his colleagues and other friends. Dean Charles H. LaWall, 1893, made the presentation. The portrait was painted by Mrs. Mary Sturmer Jones, the daughter of Dean Sturmer. The portrait was accepted for the college by President Wilmer Krusen.

Professor Moerk responded with a recital of some of the events of his career and an appreciation of the testimonial tendered him.

In addition to the personal good wishes extended by the more than three hundred friends who were present at the banquet, Professor Moerk received hundreds of telegrams and letters from all parts of the world. Mrs. Moerk sat enbanked in a veritable bower of floral tributes.

AWARD OF THE LAMME MEDAL TO EDWARD WESTON

THE 1932 Lamme Medal of the American Institute of Electrical Engineers has been awarded to Dr. Edward Weston, Montclair, New Jersey, "for his achievements in the development of electrical apparatus, especially in connection with precision measuring instruments," and will be presented at the summer convention of the institute, which is to be held in Chicago from June 26 to 30, 1933.

Previous awards of the Lamme Medal of the American Institute of Electrical Engineers have been made to Allen B. Field (1928), Rudolf E. Hellmund (1929), William J. Foster (1930) and Giuseppe Faccioli (1931).

A correspondent writes:

Mr. Weston, through his thorough fundamental knowledge of and his ability to observe and analyze chemical and physical phenomena, made important improvements in the quality and speed of electroplating, which contributed materially to the present practice in electrotyping, and nickel-, gold- and silver-plating. He also developed practical and economical methods for electrolytic copper refining.

Although the dynamo had been invented some years earlier, it had not come into practical use, and batteries were used in plating processes, placing serious limitations upon future developments. He, therefore, began the study and construction of dynamo-electric machines, and in 1875 became a partner in the firm of Stevens, Roberts, and Havell, of Newark, N. J., which engaged in the manufacture of such machines for electroplating, electrotyping, electric lighting, etc. This business was incorporated in 1877 as the Weston Company, and was consolidated in 1881 with the U. S. Electric Light Company, of which Mr. Weston served as electrician until 1888.

Mr. Weston had filed his first application for a U. S. patent on dynamo construction in 1876, and later received many patents in this field, his improvements causing phenomenal increases in the efficiency of these machines. He also invented new devices for starting, controlling and protecting them, and thus put their operation upon a practical basis.

From 1875 to 1886, he engaged in intensive development of both incandescent and arc lighting, doing notable work in the search for methods of making suitable incandescent filaments and arc light carbons.

As he had earlier been handicapped by the lack of generators suitable for use in electroplating, he now encountered, in all his researches, great difficulty in making the necessary electrical measurements with the clumsy, slow-acting instruments then available. Consequently, he soon developed and built for his own experiments a set of more practical instruments. His friends promptly wanted some of the same types, and he was soon spending much of his time on further developments of measuring equipment.

In 1883, he decided to relinquish his other interests and devote all his time to the research and development necessary to produce accurate and convenient electrical instruments. He established the Weston Electrical Instrument Company, of which he was vice-president and general manager from 1888 to 1905, and president from 1905 to 1924, when he became chairman of the board, a position which he still holds.

ELECTIONS TO THE ROYAL SOCIETY

THE council of the Royal Society, London, agreed to recommend for election as fellows the following seventeen candidates:

Blackett, Patrick Maynard Stuart, lecturer in physics, Cambridge University.

Collip, James Bertram, professor of biochemistry, McGill University, Montreal.

Crompton, Rookes Evelyn Bell, electrical engineer.

Dawson, Harry Medforth, professor of physical chemistry, Leeds University.

Doodson, Arthur Thomas, associate director of Liverpool Observatory and Tidal Institute.

Gough, Herbert John, engineer, National Physical Laboratory, Teddington.

Hammond, John, senior assistant, Animal Nutrition Institute, Cambridge.

Holmes, Gordon Morgan, physician to the National Hospital for Nervous Diseases, Queen Square, London.

King, Harold, chemist, National Institute for Medical Research, Hampstead.

Lennard-Jones, John Edward, Plummer professor of inorganic chemistry, Cambridge University.

McLeod, James Walter, professor of bacteriology, Leeds University.

Parkes, Alan Sterling, physiologist, Foulerton Student of the Royal Society.

Salisbury, Edward James, Quain professor of botany, London University.

Smith, Bernard, district geologist of H. M. Geological Survey.

Thompson, William Robin, superintendent of Farnham House Laboratory of the Imperial Institute of Entomology, London and Farnham Royal.

Tyndall, Arthur Mannering, Henry Overton Wills professor of physics, Bristol University.

Wedderburn, Joseph Henry, Maclagan professor of mathematics, Princeton University.

SCIENTIFIC NOTES AND NEWS

A TESTIMONIAL dinner to observe the eightieth birthday of Professor Elihu Thomson, of the Thomson-Houston and General Electric Companies at Lynn, Massachusetts, will be held in the Walker Memorial of the Massachusetts Institute of Technology on Wednesday evening, March 29. In the afternoon there will be a conference relating to the theoretical and experimental aspects of modern electricity, as well as to certain of its historical aspects, with particular reference to Professor Thomson's achievements.

THE honorary doctorate of the University of Paris will be conferred on Dr. Harvey Cushing, who retired last year from the professorship of surgery at Harvard University and as surgeon-in-chief of the Peter Bent Brigham Hospital.

DR. ALFRED NEWTON RICHARDS, since 1910 professor of pharmacology in the University of Pennsylvania, will be awarded the Kober Medal by the Association of American Physicians during its annual meeting in Washington, D. C., on May 9, in recognition of his work on diseases of the kidney. Dr. Rolla E. Dyer, of the U. S. Public Health Service, Washington, is the Kober lecturer for 1933. He will deliver the lecture on March 25, at Georgetown University.

AT the annual meeting of the American Society of Parasitologists, honorary foreign membership was voted to: Professor H. A. Baylis, Natural History Museum, London; Professor Dr. E. Martini, Institut für Schiffs- und Tropen-Hygiene, Hamburg; Professor Edmund Sergent, director of the Institut Pasteur d'Algérie; Professor Etienne Sergent, chef du service antipaludique à l'Institut Pasteur d'Algérie, and Professor K. I. Skrjabin, Institut d'helminthologie de l'Ecole Veterinaire, University of Moscow.

DR. WITMER STONE, of the Academy of Natural Sciences of Philadelphia, has been elected an honorary member of the British Ornithologists Union.

DR. EMIL WITSCHI, professor of zoology at the State University of Iowa, has been elected to membership in the Academy of Sciences at Halle.

DR. EDWARD H. CARY, Dallas, Texas, president of the American Medical Association, was the guest of honor at the annual dinner of the *Rhode Island Medical Journal* in Providence on February 20, which was attended by nearly two hundred physicians. Dr. Frederick N. Brown, editor of the journal, was toastmaster. A briefcase and a Texas flag were presented to Dr. Cary, who was introduced by Dr. Norman Darrell Harvey, president of the Rhode Island Medical Society.

ARTHUR W. DEAN, Winchester, chief engineer of the Massachusetts Department of Public Works, was elected president of the Boston Society of Civil Engineers at its eighty-fifth annual meeting on March 11.

WILLIAM O. MOSELEY, JR., TRAVELING FELLOWSHIPS of the Harvard Medical School, to enable students who have attended the school to continue the study of medicine in Europe, have been awarded to Dr. Stanley J. G. Nowak, instructor in surgery; to Dr. Charles V. Seastone, Jr., research fellow in bacteriology and immunology, and to Dr. Neil L. Crone, interne at the Massachusetts General Hospital.

THE Committee on Scientific Research of the American Medical Association has made a grant to Professor F. H. Pike, Columbia University, for the continuation of his work on the effects of combined experimental lesions of the central nervous system.

DR. HIRAM W. KOSTMAYER, professor and head of the department of gynecology, Tulane University Graduate School of Medicine, New Orleans, has been appointed acting dean of the school, succeeding the late Dr. Henry Daspit.

CLARENCE E. LIBBY, for several years associate professor of forestry chemistry at the New York State College of Forestry in Syracuse, has been appointed professor and head of the department of pulp and paper manufacture.

C. K. MORSE, superintendent at the Nebraska School of Agriculture in Curtis, will take up univer-

sity agricultural extension work in Lincoln in September.

DR. LORIN A. THOMPSON, head of the department of psychology at the Ohio Wesleyan University, has been appointed director of the summer session, which after a lapse of twenty-five years is to be opened again. Professor Allen C. Conger, of the department of zoology, will continue as director of the summer school at Lakeside, a summer resort, under the auspices of the Methodist Episcopal Church.

DR. J. NEEDHAM, of Gonville and Caius College, Cambridge, university demonstrator in biochemistry since 1928, has been appointed Sir William Dunn reader in biochemistry in place of Professor J. B. S. Haldane, who has accepted the chair of genetics at the University of London. Dr. Needham was visiting professor of biochemistry at Stanford University in 1929.

W. W. KAY, assistant lecturer at the University of Manchester, has been appointed lecturer in chemical pathology, and C. A. McGaughey, assistant lecturer in bacteriology, lecturer in veterinary bacteriology and hygiene.

DR. ERNEST G. PRINGSHEIM, professor of botany at the German University at Prague, has been called to the University of Frankfurt.

KENNETH HEADLAM-MORLEY has been appointed secretary of the British Iron and Steel Institute in succession to Mr. G. C. Lloyd.

DR. J. F. MCCLENDON, professor of physiological chemistry at the University of Minnesota, who has for the past twelve months been studying the relation of iodine to goiter in Japan, China, Italy and Switzerland, will arrive on the *Aquitania*, which leaves Southampton on March 29.

DR. THOMAS H. JOHNSON, of the Bartol Research Foundation of the Franklin Institute, sailed on March 15 for Mexico, Panama and Peru, where he will make measurements of the directional distribution of the cosmic radiation. The work is jointly supported by the Carnegie Corporation through the Department of Terrestrial Magnetism of the Carnegie Institution of Washington and by the foundation.

HARLAN H. ZODTNER and Frederick A. Greeley, of the Astrophysical Observatory of the Smithsonian Institution, sailed on March 4 for Suez, taking with them about six tons of equipment for installing a solar radiation station on Mount Saint Katherine, Sinai, Egypt. The authorities of the Saint Katherine Monastery on Mount Sinai have agreed to construct the observatory and trails. The expedition, financed by John A. Roebling, is expected to continue three years, cooperating with the solar radiation observatories at Montezuma, Chile, and Table Mountain, California. Mount Saint Katherine was selected after about twenty months of exploration by Mr. and Mrs. A. F. Moore. It is about 8,500 feet in altitude.

DR. HENRY C. SHERMAN, Mitchill professor of chemistry at Columbia University, will be the principal out-of-state speaker at the annual meeting of the West Virginia Academy of Science, to be held at Fairmont State Teachers College, Fairmont, West Virginia, on May 5.

AT its meeting on March 9, the Geological Society of Chicago was addressed by Professor Nevin M. Fenneman, of the University of Cincinnati, on the subject "Cyclic and Non-cyclic Erosion."

DR. ALLEN O. WHIPPLE, professor and head of the department of surgery of the College of Physicians and Surgeons of Columbia University, recently gave a series of lectures at the School of Tropical Medicine at the University of Puerto Rico.

THE twenty-fourth course of Lane Medical Lectures will be delivered by Dr. J. C. Drummond, professor of biochemistry, University College, London, on the evenings of April 3, 4, 5, 6 and 7, at Stanford University School of Medicine, San Francisco. The general title of Professor Drummond's lectures is "Recent Advances in the Biochemical Study of Nutritional Disorders." Professor Drummond will also give a lecture at Stanford University on April 11, entitled "General Survey Lines of Future Progress."

THE third International Congress for Experimental Cytology will take place in Cambridge (England) from August 21 to 26, 1933. There will be general discussions concerning the following problems: Cell respiration and cell metabolism; Cell form and function as demonstrated by recent advances in tissue culture; The electro-physiology of the cell; Entwicklungsmechanik and Explantation, and The cultivation of animal and plant viruses.

THE third expedition from the University of Michigan in a biological survey of the Maya region in Central America in cooperation with the Carnegie Institution of Washington sailed from New Orleans on March first. The party consisted of Dr. L. C. Stuart, of the Museum of Zoology, herpetologist, and Mr. C. L. Lundell, of the University Herbarium, botanist. The objective is the great savannah area lying beyond Lake Peten in the Province of the Peten, Guatemala, where detailed studies and collections of the fauna and flora will be made. It is anticipated that headquarters will be established at La Libertad in the heart of the savannah and the work carried on from that base for about four months. The first expedition in what

is planned as a twenty-year project to ascertain not only the present biological conditions but the environment under which the great Maya civilization rose and declined took place in 1931 to the region of Uaxactun far to the north in the Peten district where the Carnegie Institution has been excavating for some years. The second in 1932 was an elaborate series of explorations and studies of the cenotes and aguadas of the Yucatan peninsula, with Chichen Itza as the headquarters. The work is supported by the Carnegie Institution of Washington and the University of Michigan.

THE Laboratory of Anthropology at Santa Fe offers for the summer of 1933 twelve fellowships in field training. Four appointments will be made in archeology, working under the direction of Dr. F. H. H. Roberts, of the Bureau of American Ethnology, on Pueblo sites in Arizona. Four scholarships in ethnology are available for work under the direction of Professor Ralph Linton, of the University of Wisconsin, on the Wichita of Oklahoma. Four scholarships in linguistics are offered under the direction of Dr. Harry Hoijer, of the University of Chicago, conducting research on the Apache language in Arizona. The Fellowship Committee consists of Alfred M. Tozzer, *chairman,* Edward Sapir and Neil M. Judd.

ACCORDING to *Industrial and Engineering Chemistry, The Chemical News,* founded in 1859 by the late Sir William Crookes and for many years a publication of some importance, has apparently ceased publication. The issue for September 23 was the last weekly number and it bore a notice of change of frequency to a monthly issue, but only the October number appeared and that was late. In that number, however, the editor indicated some hope for a reorganization which would enable weekly publication to be resumed in November. However, according to *Chemistry and Industry,* the company formed under the name "The Chemical News, Limited" has now gone into liquidation and consequently the world's oldest English weekly chemical journal has come to an end. For years British and American investigators, especially in inorganic and analytical chemistry, published their results in this journal which, being a weekly, afforded means for prompt publication. Many of the discoveries of new elements were announced in its pages and for seventy-three years *The Chemical News* recorded in some form continuous progress in chemistry and allied sciences.

THE London correspondent of the *Journal* of the American Medical Association writes that at the invitation of the University of London, the Universities of Oxford and Cambridge and the Royal Colleges of Physicians and Surgeons have appointed representatives to consider, with those of the University of London, the present defects of the medical curriculum and to make suggestions for reform. The University of London was led to take action by a recommendation of the board of the faculty of medicine, which has been giving consideration to various criticisms of the medical curriculum. Representatives of the conference include Sir Farquhar Buzzard, regius professor of medicine, University of Oxford; Dr. W. Langdon Brown, regius professor of medicine, University of Cambridge; Dr. A. M. H. Gray, dean of the Faculty of Medicine, University of London; Lord Dawson of Penn, president of the Royal College of Physicians; Sir Holburt Waring, president of the Royal College of Surgeons. At the first meeting, Lord Dawson was elected chairman. The conference intends to call evidence and to review the whole course of medical education.

THE Grand Canyon National Monument, established by proclamation on January 6, is about fifty miles down the river from the point on the south rim from which tourists usually view the canyon, providing a number of new views. The proclamation covers 392 square miles and includes land already withdrawn by the Federal Government for study as to the best use to be made of it. The area is about 500 miles by motor from Los Angeles, and about 50 miles as the bird flies from Grand Canyon Village on the South Rim. Toroweap Point has an elevation of 4,750 feet, although the outer rim just above the point has an elevation of 6,500 feet. Looking downward from Toroweap Point it is 3,000 feet to the Colorado River, which appears to be a slender and seemingly insignificant ribbon of silver from this height. A huge cinder cone of volcanic origin with the mythological title of "Vulcans Throne" is also included in the monument.

THE National Park Service at Yellowstone National Park is again making preparations to distribute bison, grizzly bears and black bears to preserves, zoos, zoological gardens and parks. While the buffalo shipments will not be made until November and December, when weather conditions are more favorable, requests for bears will be handled as soon as received and the animals can be captured. It is announced that these animals will not be disposed of as pets. They are distributed primarily for purposes of exhibition and to maintain a balance in the Yellowstone Park animal world. Whereas the Park Service makes no direct charge for any of these animals, advance payment of from $55 to $70 for a buffalo, and $75 for a bear is necessary to cover the cost of crates, transportation from the point of capture to Gardiner, Montana, cost of feed, and expenses incidental to the shipment. Buffalo will be sent only as yearlings or older. In

the case of a yearling the cost f.o.b. Gardiner, Montana, is approximately $55, the animal weighing 1,000 pounds crated; while for a full grown buffalo, which weighs about 2,000 pounds crated, the cost is approximately $70. All animals are shipped express collect. Should the charges in connection with shipment amount to less than the sum remitted, a refund of the balance will be made. Requests should include information as to the number, sex and approximate age of the animals desired.

THE *Journal* of the American Medical Association reports that at a meeting of a class at the Prussian Academy of Sciences in Berlin, a preliminary report was presented by Dr. Richard Walzer, of Berlin, on a recently discovered manuscript by Galen. The manuscript, which is entitled "On Medical Empiricism," furnishes a complete Arabian translation by Hubais of the work that is known in the Occident only through a few scanty fragments. "On Medical Empiricism" is by no means a polemic against empirical medicine but rather a manual in which the eminent Greco-Roman physician for didactic reasons permits the advocates of unsupported theories to present their views, the mode of presentation being that first the dogmatizing physician attacks the empiricist and then the empiricist is given ample opportunity to defend his position. This manuscript, along with the "Subfiguratio Empirica," will be an important source of information with regard to the empirical medicine of antiquity, which, in the main, has been known only through the polemical attacks of its opponents. The manuscript contains, furthermore, some new material on the history of philosophy, especially on skepticism, and a new fragment of the writings of Democritus and of the Cynic philosopher Diogenes. Likewise the antecedents of Hellenistic empirical medicine will be clarified by Walzer's discovery.

DISCUSSION

THE LAW OF MAXIMUM NORMAL NUTRITIVE VALUE

EVIDENCE has been accumulating for many years, but especially during the past quarter century, which is in harmony with the conclusions of the writer and his associates (1) that, in a critical sense, foodstuffs can not be evaluated individually; (2) that net energy values of individual foodstuffs are fundamentally variable, and hence are not practicable standard measures of reference, and (3) that the most nearly logical, single, conventional measure of whole nutritive value is the net energy of the nutritively complete ration.

The time, therefore, seems propitious for the formulation of a principle underlying these ideas—which may be called "The Law of Maximum Normal Nutritive Value" and which may be stated as follows:

> An individual foodstuff expresses its normal and most characteristic nutritive value, for a given kind of animal, under specified conditions governing nutritive requirement, only as it is a part of a ration which is qualitatively complete and quantitatively sufficient, for the conditions existing—except as it may express the same value by virtue of the capacity of the animal temporarily to protect itself from food nutrient deficiency by drafts upon the nutritive reserves of its own body, or as it may express even higher apparent value, under certain pathological conditions, or during undernutrition, by virtue of the protective or body-sparing capacities of nutrients.

It is true that a foodstuff may seem to have a greater value when added to a markedly deficient ration than when added to a more nearly perfect one, if the entire supplementing effect of the combination is, illogically, credited to the supplementary food; but this is only because the supplement is thus credited with more than its own value, since, logically, each component of the more nearly perfect ration should be credited with greater value than it has in the less nearly perfect ration. Manifestly, there is no scientific method of apportioning the nutritive value of a diet among its components.

From the critical point of view of the principle stated foodstuffs can not be compared with each other, as to nutritive value, except with reference to a constituent, or a quality, or a capacity which they have in common—which, obviously, constitutes an incomplete and therefore imperfect basis of comparison.

This position may seem extreme, but is finally inescapable. The experimenter has only to choose between a voluntary adoption of this logically correct point of view, and a forced acceptance of the same attitude, after having been driven from one fundamentally untenable position to another until no choice remains.

A reason for the frequent failure of investigators adequately to observe this principle, in nutritional studies, is apparently the fact that, under many conditions, especially in short-time periods of experimental observation, nutritive deficiencies are, for the time being, completely masked by drafts upon the reserves of the animal body. Experimenters, therefore, often overlook the fact that under some other conditions the same deficiencies would unquestionably affect apparent nutritive values.

Fundamental nutritive requirements may be considered, in a sense, to be satisfied, from one source or other, so long as life continues—if not from the food, then necessarily from the body.

It is sometimes only through the accumulation of discordant experimental results during the course of years that the effects of failure adequately to recognize the principle to which we call attention become apparent.

In spite of the simplicity and obviousness of the foregoing expressions, the experimenter in the field of nutrition will realize that the point of view is exacting and that its full observance would require very much more knowledge of the details of nutrition than is now possessed by any one.

The experimenter can only strive toward finality of results by planning his rations in consideration of the most that is known as to nutritive values of foodstuffs and nutritive requirements of animals—which, in a few words, and in most relations, signifies that in nutritional investigation rations should be complete, perfect and sufficient, in all characteristics except the single one upon which evidence is sought.

Information which would be most helpful, in relation to the whole subject of measures of nutritive effects and requirements, is detailed knowledge of specific nutritive deficiencies in relation to the utilization of food, and as to the extent of the protection, and the time element in the protection, of the animal, from food nutrient deficiencies, which may be afforded by drafts upon its own nutritive reserves.

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THE LAW OF EFFECT

THORNDIKE[1] has just come out with an unusually striking demonstration of the law of effect, the principle that in learning a "satisfying after-effect strengthens directly the connection producing it," and Ogden[2] has hurried forward to say that after all a dynamical account of such relationships is preferable and that the retroaction of satisfaction simply means that a total temporal integration is most firmly established when it has completed itself. The time may come when the scientific world can do without the concept of cause-and-effect, or may remake it so that a cause can be subsequent to its effect. However, I do not believe that we are yet forced to any such novel view in theoretical psychology. There are at least four possibilities from which to choose:

(1) Success stamps in the preceding action retroactively—which is what the law of effect seems casually to mean, though it may be interpreted as (3) below.

(2) Success is the consummation of a process that is stamped in as a whole, so that the first part of the process actually is affected by a later part—which is, I think, nearly what Ogden means.

(3) Organization of a content, being potentially learning for ultimate reproduction, leaves a trace which persists to be affected by subsequent events. I believe that this view is really Thorndike's.

(4) "Retroactive facilitation" is actually the absence of subsequent inhibition: all mental organization would lead to memory but for the subsequent destruction of the traces, and success provides condiions for minimal destruction. This view is derived from the experiment of Jenkins and Dallenbach.[3]

The difficulty with the first two views is that, simply conceived, they imply the reversibility of time, the dependence of the present upon the future. The temporal Gestalt has, it seems to me, clear value as a scientific concept, but not in the form of (2). With such sensible and plausible alternatives as (3) and (4), why should we refuse, as Ogden does, to discuss the interrelation and mutual effects of the parts of the total integration?

EDWIN G. BORING

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IS THE SPELLING AMOEBA SACROSANCT?

I HAVE received two or three blue-pencilled copies of a statement made in SCIENCE of February 10 of the current year (page 170) to the effect that: "Generic names are sacred and their spelling may not be changed to suit the whims of writers. Amoeba can not become ameba." Inasmuch as I am one of the illiterate who have dared to use the spelling "Ameba" in a recent book, presumably to the corruption of the youth of the land, my curiosity has naturally been aroused, and I have followed up the matter a bit bibliographically. I find that the original spelling was *Amiba,* a name given by Bary de St. Vincent in 1822. Ehrenberg admits this in a paper in 1830, although he impiously changed the spelling to Amoeba and uses this form of spelling in his well-known monograph of 1838. Surely Ehrenberg had no more right in 1830 to lay profane hands on what is "sacred" than we have to-day, so the *oe* form should have no better standing than the *e* form among zoological ecclesiastics! But then why use the term at all? Taxonomists have agreed, I believe, in accordance with the "International Code of Zoological Nomenclature" to accept the generic nomenclature set forth in the tenth edition of Linnaeus' "Systema

[1] E. L. Thorndike, SCIENCE, 77: 173–175 (February 10, 1933).

[2] R. M. Ogden, SCIENCE, 77: 240 (March 3, 1933).

[3] J. G. Jenkins and K. M. Dallenbach, *Amer. Jour. Psychol.,* 25: 605–612 (1925). *Cf.* W. S. Hunter, "Foundations of Experimental Psychology," 599–605 (1929).

Naturae," and in that edition (1758) Linnaeus termed the creature in question *Volvox chaos,* later changing it to *Chaos protheus* in his twelfth edition. Thus the past nomenclature of Ameba seems to have been almost as protean as the creature itself. I suspect, however, that most of us will go on using the term Ameba or Amoeba, as our respective judgments may dictate. As to Paramecium, since the original spelling was with an *e* and not an *oe* or an *ae,* the correct form is obviously Paramecium.

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MORE OHIO MEDUSAE

IN my recent communication on an occurrence of fresh-water medusae at Akron, Ohio,[1] I made reference to the approximate number of such discoveries in the United States. Since I stated mine was the second such occurrence in Ohio, I must make this correction. I inadvertently overlooked others of recent dates.

In September, 1930, some medusae were found in Vermillion River, some in a quarry near Ashland, and in October, 1931, some in a quarry near Toledo, all localities in northern Ohio. These were reported in an abstract by Mr. Robert L. Baird, of Oberlin, Ohio.[2]

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FARADAY'S DIARY

IN a recent review of Faraday's Diary (SCIENCE, Jan. 13) I pointed out that one of the most important experiments in electromagnetic induction, described in the First Series of Experimental Researches, noted as read on November 24, 1831, is entered in the Diary under date of December 26. I ventured to suggest that the date in the Diary must be wrong. After correspondence with Mr. Thomas Martin, the editor of the Diary, I am convinced that it was right. Mr. Martin permits me to say on his authority that considerable additions were made to the First and Second Series of the Experimental Researches in Electricity after the papers were read and before they were published.

No question of priority is involved, and I make this correction only for the sake of historical accuracy.

W. F. MAGIE

SCIENTIFIC APPARATUS AND LABORATORY METHODS

RECENT DEVELOPMENTS IN GRAVITY APPARATUS

THE greatly increased interest taken in the use of geophysical methods in searching for buried geological structure, has resulted in an increased use of gravity apparatus for determining the value of g. For several decades the Von Sterneck invariable pendulum apparatus, or some modification of it, was used by geodesists for determining gravity. The observations were planned to meet the needs of physicists and chemists working in laboratories, and to enable geodesists to determine the figure of the earth or isostasists to study the distribution of densities throughout the earth's crust.

As gravity stations have become more closely spaced, it has been found that there is a definite relation between the gravity anomalies and the density of the rock close to the stations. This relationship is indicated in one way by large differences in anomalies for stations close together, of which there are several notable examples.

The Coast and Geodetic Survey, having had many calls for gravity surveys, assigned E. J. Brown, one of its field engineers, to the task of modernizing its pendulum apparatus, which had been in use since the early nineties. Brown finished his work about a year ago and the apparatus, named after him, has since been given a very severe test in the field, during which about seventy stations were established. The results have been in every way satisfactory. With the Brown apparatus one station a day can be observed, provided the distance between stations is not excessive, while with the old apparatus of the Coast Survey it was impossible to observe satisfactorily more than five stations per month.

The essential features of the Brown apparatus are:

(1) The receiver supports are about in the same horizontal plane as the knife edge on which the pendulum swings. This arrangement greatly reduces the flexure of the apparatus.

(2) The oscillations of the pendulum are made to actuate a photoelectric cell and the impulses are amplified until they operate the chronograph pen. With this arrangement the time signals sent from the Naval Observatory by radio can be compared directly on the chronograph sheet with the oscillations of the pendulum and a chronometer is not needed as an intermediary timepiece.

(3) Another very important feature of the Brown apparatus is that most of the auxiliary parts of the gravity equipment are installed permanently in an automobile truck. These parts include the chronograph, radio apparatus used for receiving the signals, switchboard, batteries, etc. The only important part

[1] SCIENCE, 77: 87, 1933.

[2] *Ohio Jour. Science,* 32: 323, 1932.

of the apparatus that needs to be taken out of the truck on arrival at a new station is the pendulum receiver.

(4) The pendulum receiver is designed in such a way that the pendulum can be clamped in a safe position without removing it, after observations have been made at a station. The receiver containing the clamped pendulum is then placed in an automobile truck and carried to the next station. At the new station the apparatus can be set up and the pendulum released and started in operation within a few minutes. A few electrical connections between the case and the apparatus installed in the truck and the erection of a short antenna completes the necessary arrangements. Ordinarily, the receiver remains evacuated during a whole season, and this helps to maintain a more uniform temperature of the pendulum.

There are several other novel features in the Brown apparatus, but they are of less importance than those mentioned. A brief account of the apparatus will be found in Transactions of the American Geophysical Union, dated June, 1932.

The Brown apparatus at the time of this writing is being used for a gravity survey in Cuba. It is expected that observations will be made at approximately seventy stations in that island, which were selected by the geologists of the Atlantic Refining Company of Cuba. The work is being done by the cooperation of that company, the Coast and Geodetic Survey, the Naval Observatory and Professor Richard M. Field, of Princeton University, chairman of the Committee on Geophysical and Geological Study of Oceanic Basins and their Margins of the American Geophysical Union.

Another new gravity apparatus, called the Lejay-Holweck Gravimeter, is receiving to-day a great deal of attention. This apparatus consists of a base on which is mounted a vertical frame that supports rigidly a short thin strip of elinvar extending vertically upward. Attached to the upper end of the elinvar strip is a bob of quartz whose coefficient of expansion is close to zero. The whole apparatus can be carried in a small box or case and is easily transported by hand.

The bob supported by the elinvar strip oscillates under the combined action of gravity and the elasticity of the strip. The mass of the bob is such that it is almost exactly balanced by the elastic force of the strip. By means of this arrangement the pendulum is given a very long period and in consequence is very sensitive to variations in the pull of gravity. This makes it unnecessary to have a very exact time control for measuring the periods of oscillation. It is stated that the apparatus is one hundred times more sensitive than the ordinary gravity pendulum and, therefore, an error in time may be tolerated that is one hundred times as great as that permissible with the usual pendulum apparatus.

In the *Comptes Rendus* of the Academy of Sciences of January 3, 1933, is a short article by Dr. Lejay telling of a gravity survey that had been made by him in the northwestern part of France. Forty determinations were made with the Lejay-Holweck apparatus in the two months of October and November, 1932. During two weeks of that period no observations were made. As an indication of the rapidity with which the observations were carried on, it is stated that on October 7, 1932, and again on October 11, observations were made at three stations. On each of several other days two stations were established. The average distance between the stations in this survey was about 40 kilometers. During the period, observations were made in Paris on three different dates and the range in the values of gravity at that station was only one part in a million. It is stated by Lejay that wherever he found it impracticable to find a stable support for his apparatus he preferred to secure what he considered a fairly accurate determination with an uncertainty of about two parts in a million of gravity rather than to delay the progress of his work. An accuracy of two parts in a million is really quite satisfactory for most purposes to which gravity data are applied. During the 7,000 kilometers traveled in an automobile during this gravity survey the pendulum did not change.

Lejay states that as a result of his campaign in northwest France one may be assured that it is possible for a single observer without any assistance and without great fatigue to complete one station per day, provided a means of rapid transportation is at the disposal of the observer.

It is understood that the computations for the topographic and isostatic reductions of the gravity stations in France will be made shortly. It will be of interest to learn the results, for until now there have been but few gravity stations in France for which the isostatic anomalies are available.

The Brown and the Lejay-Holweck types of apparatus are the only new ones known to the writer with which extensive and successful field work has been done. Other types of gravity apparatus are in the process of development. One is the apparatus of Fred E. Wright, of the Geophysical Laboratory of the Carnegie Institution of Washington, which is based on the use of horizontal helical springs to balance the pull of gravity on a weight at the end of a lever arm supported in a horizontal position by the torsion of the springs. Wright has developed his apparatus to the point where he was able to make some tests with it outside of the laboratory. No definite information is available as to the character of the results obtained during these tests.

An apparatus has been in the process of development at the office of the Geodetic Institute at Potsdam, Germany. This one has as its essential feature the balancing of a column of mercury against a fixed volume of gas. No definite reports of progress are available, but the writer has been led to believe from conversations and correspondence that the apparatus gives promise of being quite effective.

A new type of gravity apparatus has recently been developed in Norway. A description of the apparatus and of the methods employed in its use is contained in articles by K. Wold and G. Jelstrup, which appeared on pages 269 to 279 of *Gerlands Beiträge zur Geophysik*, No. 36, 1932.

It is well known that one or more of the petroleum companies of this country have been working on gravity apparatus and methods, but no information regarding them is in print. It is known, however, that a method has been employed whereby the oscillations of a pendulum kept swinging at a central field base station are transmitted by radio to surrounding stations at which they are compared directly with the oscillations of the field pendulums.[1] With such a method the required accuracy can be obtained by a short series of observations and any number of gravity parties can operate simultaneously in the field within a reasonable distance of the base. This method should be very effective in making an intensive gravity survey of a comparatively large area, but for the usual gravity work the expense of operating the base station with the transmitting apparatus would scarcely be justified.

It may be said without question that notable progress has been made recently in the improvement of gravity methods and apparatus, and it is very probable that even further advance will be made in the very near future. Gravity surveys will undoubtedly play an ever-increasing part in geophysical and geological studies designed to disclose buried structure, a matter of great importance in the search for petroleum, water and minerals. Anticlines, domes, synclines and masses of heavy rock or ore may be indicated by the values of gravity at stations located immediately above or very close to them.

WILLIAM BOWIE
U. S. COAST AND GEODETIC SURVEY

SPECIAL ARTICLES

NEW HARDY SEEDLESS GRAPES

A PROJECT[1] in breeding grapes which has for its aim the development of hardy seedless clons of merit has now given 28 seedlings that bear seedless or near-seedless fruits and that are hardy in the climate of central New York. One of these plants has already been reported,[2] but most of them fruited for the first time in 1932.

Seedless grapes of various types occasionally arise directly from seeded grapes, presumably either by mutation, by segregation or by some particular combination of complementary factors. Such plants usually bear viable pollen and hence they may be employed as pollen parents in crosses with seeded plants in the effort to take advantage of any hereditary values which seedlessness may possess in obtaining more seedless individuals among the offspring.

The new seedless grapes thus far obtained in this project are all the progeny of hardy seeded grapes crossed with the tender seedless varieties Sultanina, Rose Sultanina and Black Monukka. According to the investigations of Goodspeed,[3] Susa[4] and Pearson,[5] in these seedless grapes fruits are for the most part produced only after pollination and fertilization, and hence the parthenocarpy is stimulative rather than spontaneous.

Vines of the tender seedless grapes are grown in the courts between greenhouses at the New York Botanical Garden, where they frequently flower at the time when the pollen can be used on hardy grapes in bloom at Geneva. Rather large numbers of seeds (several thousand) were obtained in the crosses, but a large percentage of the F_1 died in the nursery or vineyard, evidently because of tenderness inherited from the vinifera parent. Of the seedlings that survived some have seeded fruits and some have seedless or near-seedless fruits.

The occurrence of seedless grapes in considerable numbers in the F_1 generation of these crosses is a matter of importance to the practical results of the breeding effort. The occurrence of both seeded and seedless individuals in this generation is a result of significance in considering the heredity of seedlessness. It appears that seedlessness of the type here concerned is not a simple character in inheritance and that in these crosses one or both parents are hetero-

[1] This method was suggested by C. A. Heiland in 1927 in a paper given before the Section of Geodesy of the American Geophysical Union. See Bulletin No. 61 of the National Research Council, pp. 66–71.

[1] By permission of the authorities of The New York Botanical Garden the writer has cooperated with the Department of Horticulture of the State Experiment Station at Geneva, N. Y., in this project.

[2] A. B. Stout, "A New Hardy Seedless Grape," *Jour. Heredity*, 19: 316–323, 1928.

[3] T. H. Goodspeed, Paper presented in Section G, 73rd meeting A. A. A. S., December 28, 1920.

[4] T. Susa, "Sterility in Certain Grapes," Mem. Hort. Soc. N. Y. 3: 223–232, 1927.

[5] Helen Pearson, "Parthenocarpy and Seedlessness in *Vitis vinifera*," SCIENCE, 76: 594, 1932.

zygous for certain of the complementary factors involved.

A preliminary study of the seed-like structures in the mature fruits of these new seedless grapes shows several degrees of development. In a few cases there are only tiny rudiments of seeds, quite as exist in the fruits of the Sultanina grape. But in most cases there is some development of the tissues of the seed coats, but the structures, even when their size approaches that of a seed, are either without embryo and endosperm or with only traces of them and are so soft and pulpy that they are not noticed when the fruits are masticated in eating. It appears that the type of seedlessness in these plants corresponds to that of the pollen parent, but that the inhibition in the development of the seeds which results in their abortion is less complete in most of them.

The seedless plants already obtained are being utilized as pollen parents in crosses with sister plants that have seeds. The latter are being selfed and crossed to obtain a second generation and they are being used in back crosses with the seedless parents. The results should give further data on hereditary behavior, and, it is hoped, provide more of the seedless grapes.

Several of the seedlings which bear seedless or near-seedless fruits possess considerable merit. For these the clusters are well filled and of good size or even large. In size the berries range from larger than Delaware fruits to nearly the size of Concord. The colors include green, amber, red, mottled red and shades of black. In quality there is considerable variation, but the best are vinous, sweet and meaty. Several ripen early. The most promising of these grapes are being propagated for trial under cultural conditions.

A. B. STOUT

NEW YORK BOTANICAL GARDEN

THE OCCURRENCE OF ROTENONE AND RELATED COMPOUNDS IN THE ROOTS OF CRACCA VIRGINIANA[1]

CRACCA VIRGINIANA, the most abundant species of the genus Cracca indigenous to the United States, has recently been reported as possessing insecticidal properties.[2] This, together with the fact that other species of Cracca, namely, *C. toxicaria* from South America and *C. vogelii* from Africa, have yielded substances related to the rotenone group of fish poisons,[3] has made a chemical study of the American species interesting and desirable. Such an investigation has been in progress and to date the following results have been obtained:

Ether extraction of the roots of the plant yielded from 4 to 6 per cent. of resinous materials having a pleasant characteristic odor. The extract, when tested as a fish poison, showed essentially the same toxicity as pure rotenone. It contained 9 per cent. methoxyl[4] and in many ways resembled the non-crystallizable extractives from derris and cubé roots.[5] Attempts to obtain individual major constituents by distillation, crystallization or the formation of derivatives were for the most part unsuccessful, although four substances were obtained in small quantities. These were rotenone, dehydrorotenone, tephrosin and a colorless crystalline material, $C_{22}H_{24}O_4$, whose M.P. is 131°.

The rotenone was obtained by dissolving one part of the resin in an equal part of *n*-butyl ether and allowing the solution to crystallize for from two to three weeks. The yield was usually about 5 per cent. of the weight of the resin, but apparently much more rotenone was present which did not crystallize because of the complex nature of the mixture. This was shown by the fact that a slightly more dilute solution failed entirely to crystallize or at most gave only traces of crystals, and also by the fact that solutions of the resin in other solvents, from which rotenone readily crystallizes from very dilute solutions, would not crystallize.

Dehydrorotenone was obtained from the resin in approximately 2 per cent. yield by treating the material in a methanolic solution with alkali (50 gm. resin, 200 cc. methanol and 0.5 gm. potassium hydroxide). Sometimes crystallization occurred in a short time, and again a month or more was required for the process to take place. The dehydrorotenone was frequently contaminated with material which appeared to be a dehydro derivative of a somewhat higher molecular weight. The first specimen obtained, for example, melted sharply at 217°. It gave analytical values approximately half-way between that required for dehydrorotenone and dehydrotoxicarol and could not be further purified. Hydrolysis with alcoholic alkali, however, gave a fair yield of derrisic acid, and examination by the optical immersion method[6] showed that much of the material was dehydrorotenone. This particular phenomenon is the same as was recently reported for certain naturally occurring mixtures of dehydrodeguelin and dehydrotoxicarol.[7] Other specimens of the dehydro

[1] From the Insecticide Division of the Bureau of Chemistry and Soils, United States Department of Agriculture, Washington, D. C.

[2] Little, SCIENCE, 73, 315 (1931); *Jour. Econ. Ent.*, 24: 743 (1931).

[3] Clark, *Jour. Am. Chem. Soc.*, 52, 2461 (1930); 53, 729 (1931).

[4] A ligroin (B.P. 40–60°) extract was employed for this purpose.

[5] Clark, SCIENCE, 71: 396. 1930.

[6] The optical identifications involved in this communication were performed by George L. Keenan, of the Food and Drug Administration, U. S. Department of Agriculture.

[7] Clark and Keenan, *Jour. Am. Chem. Soc.*, 55, 422, 1933.

derivative from the same or other samples of resin were easily purified and identified by melting-point, mixed melting-point and optical properties.

Tephrosin was obtained by removing the methanol from the dehydrorotenone mother liquors, dissolving the residue in approximately an equal volume of *n*-butanol and allowing the solution to crystallize over a period of several weeks. The material was purified and identified by melting-point, mixed melting-point and optical properties.

The fourth substance, $C_{22}H_{24}O_4$, sometimes crystallized in small amounts from the alkaline methanolic solutions upon standing. A small quantity could always be obtained by adding approximately 5 per cent. of water to the alkaline alcoholic solution and allowing the turbid liquid to stand until it cleared. Crystallization usually occurred. If this did not take place, the oily insoluble layer in the bottom of the flask was dissolved in boiling petroleum ether and concentrated to about one fifth of its volume. Upon standing the solution crystallized. The material was purified by recrystallization from petroleum ether. It consisted of colorless rods which melted at 131° and gave in alcoholic solution a greenish purple color with ferric chloride, but it did not dissolve in aqueous alkali. Analysis for carbon and hydrogen and molecular weight determinations showed it to have the formula $C_{22}H_{24}O_4$. The material reacted with hydriodic acid in a Zeisel apparatus, giving an alkyl iodide, but the results were of such a character as to show that probably neither methoxyl nor ethoxyl groups were present. The material in a concentration of 1–100,000 when tested for toxicity, employing goldfish as test animals, was inert.

The yields of tephrosin and the C_{22} compound were small and variable, but, as with rotenone, there were ample indications that much more material than was obtained was present in the resin. In all probability the complex character of the extractives inhibited the crystallization of the individual constituents.

While the results here recorded account for only a small portion of the extractives of *Cracca virginiana*, it is interesting that this is the first native plant of the United States in which members of the rotenone group of fish poisons have been found.

E. P. CLARK

EFFECT OF TEMPERATURE ON EVERSPORTING EYE COLOR IN DROSOPHILA MELANOGASTER[1]

OUR x-ray experiments have produced three mottled-eyed stocks.[2] All are caused by some change in the normal allelomorph at the white locus of the x-rayed wild type sex chromosome. Regular males receiving a treated X-chromosome, and regular females heterozygous for a treated X and for white eye color, have mottled eyes.

Since the mutation rate varies directly with temperature in *Drosophila melanogaster*,[3] it might be expected that temperature would influence such conditions of genetic instability. Similar cases of eversporting in other forms have been tested for effect of temperature. Eyster[4] found that strains of maize with variegated pericarp color raised in Arizona showed less extreme variegation patterns than the same strains raised in a cooler climate in California. Demerec,[5] on the other hand, found that a difference of 10° C did not affect mutable miniature in *Drosophila virilis*.

Preliminary tests at 29°, 24° and 18° C show that the cooler the temperature at which the flies are raised the larger the light areas of mottled eyes in our stocks. Temperature affects viability as well as eye color. Mottled-2 is almost completely lethal to males at 18° and 24°, but at 29° a fair proportion of the expected males survive, demonstrating that genetic constitution may be a factor in determining the survival value of an organism in an unfavorable environment.

This temperature effect offers a means of determining the larval stage at which mottling occurs, which may furnish a clue as to the mechanism involved. Eyster's work and ours both indicate that the incidence of eversporting varies inversely with temperature, which seems to imply that something other than regular gene mutation is responsible for these cases of unstable genetic constitution.

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[1] From the Rockefeller Institute for Medical Research, Department of Animal and Plant Pathology, Princeton, N. J.; and the Department of Biology, School of Hygiene and Public Health, Johns Hopkins University, Baltimore, Md.

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